Extended Abstract submission to ISER http://www.iser02.unisa.it/ conference due by email 27 February

Performance and 6DOF Ground Truth Evaluation of the GESTALT Mars Rover Surface Navigation System: First Results

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One of the most challenging aspects of building an autonomous rover navigation system is how to quantify the final system's performance. Simple one-shot demonstrations are often employed for this purposes but, while intuitively appealing, these are not reproducible and can make it difficult to analyze failures. We set out to improve this process, by collecting onboard data in conjunction with externally measured ground truth, during dozens of runs with a prototype Mars rover. In this paper we outline our approach and present preliminary results from the Athena Software Development Model (SDM) Summer 2001 Datasets.

ONBOARD DATA: The Athena SDM, 104 cm x 84 cm x 150 cm, was built specifically as a prototype Mars rover. It is commanded using a simple "goto waypoint" command, with a desired location given in X,Y world coordinates with a radial tolerance (a traverse is "successful" if it stops within an X meter-radius circle centered at the goal point). Its navigation system, Grid-based Estimation of Surface Traversability Applied to Local Terrain (GESTALT), uses stereo image pairs and an onboard position estimate derived from wheel odometry and an Inertial Measurement Unit to find a safe path that gets it closer to its goal. GESTALT moves the vehicle in short arcs, nominally pausing to acquire new terrain images every 35 cm. The onboard navigation decision-making behavior can be reproduced exactly by archiving and playing back the geometric camera models, stereo image pairs, and position estimates. These data comprise the bulk of the archive representing a traverse.

GROUND TRUTH DATA: A surveyor's ranging theodolite was employed to collect ground truth measurements with 2 millimeter precision. Both rover position and orientation were measured using a least squares fit of three or more points per location, resulting in an overall 6 degree of freedom (X, Y, Z, pitch, roll, yaw) ground truth measurement. Selected obstacles were archived by approximating them as ellipsoids and measuring radial distance along 3 orthogonal axes. Rover ground truth was acquired after each 35 cm arc step, while static obstacles and testbed references were measured at most once per day. These measurements and the data collected onboard comprise a complete traverse dataset.

Data representing nearly 100 autonomous rover traverses of 5 meter to 17.5 meter distances were collected. Some of these runs were incomplete or had to be terminated due to software bugs, since the data was collected during development of the overall navigation system. But over 3600 ground truth measurements were made, resulting in over 600 precisely-measured 35 cm motions, comprising dozens of complete traverses. We present data derived from these runs in several forms.

First, we plot the onboard estimated position versus the actual ground truth trajectories. These data are illustrated graphically and as animations from arbitrary viewpoints.

Second, we derive models of the system's position estimation performance by fitting the measured differences into appropriate distributions. Understanding the distribution of the positioning errors will enable us both to plan more realistic traverses, and to add realistic noise models to rover traverse simulations. Preliminary analysis of the actual distance traveled along each arc indicates an uncertainty sigma of 13%, or nearly 5 cm.

Finally, we classify the performance of each traverse, to see how many times the rover successfully navigated into the goal circle. Preliminary analyses of 49 runs, 27 of which have complete ground truth, will be presented.